1 of 1

ANL/EP/CP--79739-Rev.

Conf-930928--6-Rev.

REVISED PAPER

NEUTRONICS OF A D-Li NEUTRON SOURCE - AN OVERVIEW*

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

**Itacil C. Gomes and Dale L. Smith
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439 USA**

The submitted manuscript has been authored by a contractor of the U. S. Government under contract No. W-31-109-ENG-38. Accordingly, the U. S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U. S. Government purposes.

November 1993

- * Work supported by the U.S. Department of Energy, Office of Fusion Energy, under Contract No. W-31-109-Eng-38.

Paper presented at the Sixth International Conference on Fusion Reactor Materials, September 27 - October 1, 1993, Stresa, Lago Maggiore, Italy.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Neutronics of a D-Li Neutron Source - An Overview*

Itacil C. Gomes and Dale L. Smith
Fusion Power Program - Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439
U.S.A.

ABSTRACT

The importance of having a high energy (14 MeV) neutron source for fusion materials testing is widely recognized. The availability of a test volume with easy accessibility, with a radiation environment similar to the one expected for a fusion reactor, and with dimensions large enough to accommodate several small samples or a small blanket mock-up are requirements impossible to meet with the existing reactors and irradiation facilities. A D-Li neutron source meets the above mentioned requirements and can be built today with well known technology.

This paper describes some relevant topics related to beam target configuration, neutron flux spectrum, and nuclear responses for a D-Li neutron source. The target-beam configuration is analyzed for different beam cross sectional areas and trade-offs between the area of the beam and related quantities such as available volume for testing, peak fluxes, and flux or nuclear responses gradient are presented.

The conclusion is that the D-Li neutron source has the necessary characteristics to be the option of choice for IFMIF.

* Work supported by the U.S. Department of Energy, Office of Fusion Energy under Contract No. W-31-109-Eng-38.

I. Introduction

The importance of having a high energy (14 MeV) neutron source for fusion materials testing is widely recognized. The availability of a test volume with easy accessibility, with a radiation environment similar to the one expected for a fusion reactor, and with dimensions large enough to accommodate several small samples or a small blanket mock-up are requirements impossible to meet with the existing reactors and irradiation facilities. This paper describes part of a study performed to evaluate the performance of a D-Li neutron source based on the requirements for a fusion materials irradiation facility, Doran [1].

The use of the D-Li reaction for a high flux irradiation facility presents advantages when compared with other possible candidate reactions such as T-H₂O, Doran [2], Hassanein [3] (based on the neutron yield, energy deposition on target, and tritium handling) and D-Be, Cierjacks [4] (based on the energy dissipation on the target). A high intensity neutron source using the D-Li reaction can be obtained by impinging energetic deuterons (from 20 to 50 MeV) on a fast flowing liquid lithium jet. The deuterons interact with the atoms of the lithium jet either losing part of their energy (Coulomb interaction) or producing nuclear reactions some of which produce neutrons (${}^7\text{Li}(d, np){}^7\text{Li}^* \rightarrow T + \alpha$, ${}^7\text{Li}(d, 2n){}^7\text{Be}^* \rightarrow {}^3\text{He} + \alpha$, ${}^7\text{Li}(d, n){}^8\text{Be}$, ${}^7\text{Li}(d, 3n){}^6\text{Be}$, and others of lesser importance, Cierjacks [4], Hassberger [5]). The neutron

yield for the D-Li reaction (number of neutrons produced per incident deuteron) was evaluated, Mann [6] to be between 0.055 and 0.06. The angular and energy distributions of the generated neutrons as a function of the deuteron energy was previously derived for the FMIT project, Mann [6]. A schematic of a D-Li neutron source is presented in the Figure 1.

The interaction of deuterons with the lithium jet will produce a considerable energy deposition on the bulk of the jet, Hassanein [7]. The jet velocity has to be adjusted to meet stability and vaporization criteria. Focusing the deuteron beam on a small area on the jet produces larger energy deposition per unit volume than spreading the beam.

In this work trade-offs between the size of the beam and neutron spectrum and nuclear responses, such as DPA, helium production, and nuclear heating, are analyzed. The basic configuration used was a single beam carrying 250mA of current with six different beam cross sectional areas (3x1, 12.5x2, 7x7, 17x3, 10x10, and 20x20cm²). The deuteron incident energies considered were 35 and 40MeV. The test assembly region (region where the samples are to be irradiated) was divided in thousands of mesh volumes and the neutron flux and nuclear responses evaluated at each mesh. The neutron/gamma-ray transport calculations were performed with the use of the Monte Carlo code MCNP, Briesmeister [8], and the neutron flux-spectra were folded with nuclear response data, when necessary, by a post-processor

code described elsewhere, Gomes [9].

II. Neutron Energy Spectrum from the D-Li Source.

The D-T reaction produces neutrons within a narrow range of energy around 14MeV. The D-Li neutron source produces neutrons with energies from the eV's up to 50MeV (for a 35 MeV deuteron incident energy) but most of the neutrons produced (85 to 95% depending on the incident deuteron energy) range within 0 to 15 MeV, Gomes [10]. Inside the blanket and shield of a fusion reactor, the D-T neutrons from the plasma will suffer a slowing-down process which will produce a neutron energy spectrum (which varies with the position and materials) ranging from the thermal neutrons to about 15 MeV.

Figure 2 presents five curves, one being the normalized neutron energy spectrum (per 1 MeV energy intervals) at the ITER first wall (design option which uses liquid lithium as a coolant and breeding material, calculated using 1-D model and considering the slowing-down process of the neutrons). The other four curves are of the D-Li source spectrum for a $7 \times 7 \text{ cm}^2$ beam size. These curves represent the collided (with material inside the test assembly) and uncollided (without material inside the test assembly) neutron flux-spectrum at two different positions; at the back plate and at 10cm from the back plate, inside the test assembly region, in the direction of the beam. Considering 1MeV energy intervals, the ITER first wall spectrum peaks at two energy groups; below 1MeV and at 14MeV. The D-Li neutron flux-spectra do not peak at 14 MeV but covers all the energy range of the fusion

reactor spectrum. At 10cm from the back plate the D-Li spectrum is rather flat over the range from 2-4 to 15 MeV for both collided and uncollided flux due to the preferentially forward directed high energy neutron generation at the source. The number of neutrons with energy above 20MeV of the D-Li spectra accounts, in the cases presented, for less than 12% (at 10cm) and 5% (at the back plate) of the total number of neutrons.

III. Nuclear Responses at the Back Plate

The importance of evaluating nuclear responses, such as DPA rate, helium production, nuclear heating, among others, at the back plate is essentially to infer the expected lifetime of the back-plate and to give an upper boundary value for a given response.

The magnitude of the nuclear responses at the back plate varies with the inverse of the ratio between the areas of the beam, to a power that varies from 0.7 to 0.9. This means that increasing the cross sectional area of the beam by some factor, the nuclear response decreases by a factor less than the ratio between the areas of the beams. At the same time, the energy density deposition (due to the interaction of the deuterons with the lithium target) scales linearly to the inverse of ratio between the beam cross sectional areas. This fact gives, for the same deuteron current, some advantage to increasing the beam size to reduce the energy density deposition while obtaining acceptable

nuclear response levels.

Figure 3 presents a plot of the DPA rate on a SS-316 back plate as a function of the beam cross sectional area for 35 and 40MeV deuteron beams. It can be seen that displacement rates as high as 950 DPA/yr (for a 3x1cm beam cross sectional area with 40 MeV deuterons) or as low as 15 DPA/yr (for the 20x20cm beam cross sectional area with 35MeV deuterons) can be achieved. It is clear that the stainless steel would not last long under a 950 DPA/yr (the average DPA rate at the first wall of a fusion reactor is about 10-50 DPA/yr) neither would the jet support the very high energy density deposition associated with this beam size. On the other hand a maximum DPA rate of 15 DPA/yr may not be enough for performing accelerated materials testing. Figure 4 presents similar results for the helium production on the back plate.

Another important parameter to evaluate the lifetime of the back plate is the heat deposition and the corresponding temperature of operation. Figure 5 presents the heat deposition due to both, neutrons and gamma-rays as a function of the beam cross sectional area. This figure shows that a heat deposition as high as 400 Watts/cm³ or as low as 7.5 Watts/cm³ for beams of 3x1cm with 40MeV deuterons and 20x20cm with 35MeV deuterons can be expected, respectively.

IV. Nuclear Responses Inside the Test Assembly Region

Analyses of distributions of responses such as DPA, helium production, nuclear heating, and others, is more useful than the analysis of the neutron flux distribution because they account for variation in the neutron energy spectrum and can easily be translated, for the same material, from one facility to another. Figures 6 and 7 present the SS-316 DPA rate profile along the beam axis and perpendicular to the beam axis, respectively, for six different beam cross sectional areas (3x1, 12.5x2, 17x3, 10x10, and 20x20cm²). These curves refer to calculations which include material inside the test assembly region (SS-316 at 30% density for the first 15cm and at 100% density from 15 to 50cm). It can be seen that the larger the beam cross sectional area the smaller the gradient of the DPA rate. Another characteristic that should be pointed out is the existence of a gradient in both directions; that of the beam axis and that perpendicular to the beam axis. The latter gradient also gives an advantage to larger beams due to the essentially flat profile across the beam cross sectional area.

The ratio between helium production (appm) and DPA is an important parameter to consider when analyzing irradiation facilities. When irradiating materials for fusion applications, helium to DPA ratios similar to those expected for a fusion reactor are fundamental to produce meaningful data. The expected value, at the first wall, for this ratio is between 10 and 15 (appm/DPA) for the stainless steel. Figure 8 presents the

calculated helium to DPA ratio inside the test assembly region for the SS-316 using a 10x10cm beam cross section and 35MeV deuterons. It can be seen that values in the range of 9 to 15 appm/DPA are obtained in a large portion of the test region, consistent with the requirements for testing of typical structural materials for fusion applications.

The testing volume with nuclear responses above a specified threshold value is another key parameter to be considered. Figure 9 presents the volume above a DPA threshold value as a function of the DPA threshold value for six different beam cross sectional areas having the same 250mA of current and 35MeV deuterons. It can be noticed that the available volume is not strongly dependent on the size of the beam and that using 250mA of current it is possible to obtain about 1 liter with DPA rates above 10 DPA/yr.

Conclusions

The D-Li neutron source produces a radiation environment well suited for fusion material testing. Nuclear response rates in excess to those expected for a fusion reactor allow for accelerated testing. The available testing volume above a DPA threshold value is large enough to accommodate several small size samples during the same irradiation cycle. The enlargement of the beam cross sectional area reduces the peak energy deposition inside the jet and at the same time reduces peak values and gradient of neutron flux and nuclear responses in the test region.

References

- [1] D. G. Doran, personal communication.
- [2] D. G. Doran, S. Cierjacks, F. M. Mann, L. R. Greenwood, and E. Daum, "Neutronics Comparisons of D-Li and T-H₂O Neutron Sources," these proceedings.
- [3] A. Hassanein, D. L. Smith, D. K. Sze, and C. B. Reed, "Analysis of the Tritium-Water (T-H₂O) System for a Fusion Material Test Facility," ANL/FPP/TM-261, Argonne National Laboratory (1992).
- [4] S. Cierjacks, editor, "Neutron Sources for Basic Physics and Applications," OECD/NEA report, Pergamon Press (1983).
- [5] J. A. Hassberger, "Preliminary Assessment of Interactions Between the Fmit Deuteron Beam and Liquid Lithium Target," HEDL-TME 82-28, Hanford Engineering Development Laboratory (1983).
- [6] F. M. Mann, F. Schmittroth, and L. L. Carter, "Neutrons from D+Li and the FMIT Irradiation Environment," HEDL-TC-1459, Hanford Engineering Development Laboratory, (1981).
- [7] A. Hassanein and D. L. Smith, these proceedings.

- [8] J. F. Briesmeister, editor, "MCNP - A general Monte Carlo code for Neutron and Photon Transport," LA-7396-M, Los Alamos Scientific Laboratory, NM, (1991).
- [9] I. C. Gomes and D. L. Smith, "Analysis of the Neutron Generation from the D-Li Neutron Source," ANL-TM (to be published).
- [10] I. C. Gomes and D. L. Smith, " Characteristics of the Neutron Flux from a D-Li Neutron Source," ANL-TM (to be published).

Figure 1. Schematic of the deuteron beam, lithium target and irradiation test cell for a D-Li neutron source.

Figure 2. Comparison of the normalized neutron energy spectrum from the D-Li neutron source and from the ITER (lithium blanket) first wall. In the legend "BP" indicates back-plate, "coll" collided flux, "unc" uncollided, and "10 cm" indicates the position inside the test assembly.

Figure 3. DPA rate at the back-plate as a function of the beam cross sectional area for 35 MeV and 40 MeV deuterons with a beam current of 250 mA.

Figure 4. Helium-4 production rate at the back-plate as a function of the beam cross sectional area for 35 and 40 MeV deuteron beams with 250 mA of current.

Figure 5. Nuclear heating due to neutrons and gamma-rays at the back-plate as a function of the beam cross sectional area for 35 and 40 MeV deuteron beams with 250 mA of current.

Figure 6. SS-316 dpa rate profile along the beam direction for six different beam cross sectional areas with 250 mA of current and 35 MeV deuteron energy.

Figure 7. SS-316 dpa rate profile in the direction perpendicular to the beam and to the jet for six beam cross

sectional areas with 250 mA of current and 35 MeV deuterons. The profiles for the 12.5x2, and 17x3 cm beams are presented for the largest cross sectional dimension of the beam.

Figure 8. Helium production (appm/year) to dpa rate (dpa/year) ratio. Profile along the beam direction for a 250 mA, 35 MeV, 10x10 cm deuteron beam.

Figure 9. Volume above a threshold value as a function of the threshold value for 6 beam spot areas, considering beams with 35 MeV deuterons and 250 mA of current.

Li(d,nx)y

Normalized Neutron Energy Spectrum from ITER and D-Li Spectrum computed at 1st wall and back-plate

Maximum SS-316 DPA Rate on the Back Plate
250mA Deuteron Beam - SS-316 in the Test Cell

Maximum Helium-4 Production on the Back Plate 250mA Deuteron Beam - SS-316 in the Test Cell

Maximum Nuclear Heating in the Back Plate 250mA Deuteron Beam - SS-316 in the Test Cell

Gradient of the SS-316 DPA rate Along Beam Direction Beam Current = 250mA – Deuteron Energy = 35 MeV

Gradient of the SS-316 DPA rate Perpendicular to Beam
Beam Current = 250mA – Deuteron Energy = 35 MeV

Helium [appm] to DPA ratio for a 10x10cm Beam Size
250mA, 35MeV deuterons – Material inside the test cell

Volume with DPA rate greater than a specified threshold
 35MeV, 250mA Deuteron Beam - 30% dense 0-15cm 100% remaini

DATE

FILMED

2/23/94

END